# THE BREVARD STREET

# MERCURY ARC RECTIFIER

# SUBSTATION

# of the

# BALTIMORE AND OHIO RAILROAD

TAU BETA PI INITIATION THESIS

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COLLEGE OF ENGINEERING

ELECTRICAL

CLASS OF 1940

# SUMMARY

The subject of this paper is a modern mercury arc rectifier substation constructed to replace a rotating substation which had to be moved or abandoned.

The paper opens with the "Early History" designating the events leading up to the construction of the substation. This is followed by a description of the building and operating equipment, illustrated with pictures. The theory of operation of a mercury arc rectifier is given with a brief description of a rectifier tank unit which is also illustrated by a picture showing the operating parts. A discussion of the essential features of Mercury arc rectification, such as:

Efficiency,

Voltage Regulation, and power factor are drawn out followed by a mention of the inspection and maintenance of the substation.

In the Conclusion, the inher~~r~~ent advantages of the rectifier unit is brought out by a comparison with rotating equipment.

## BIBLIOGRAPHY


Mr. J. H. Davis ------------------ Chief Engineer of Electric Traction
Baltimore and Ohio Railroad

Mr. R. L. Erwing ----------------- Substation Operator
Brevard Street Rectifier Substation

General Electric Review

Railway Electric Journal

Westinghouse Electric Engineer

Bryant and Johnson
Alternating Current Machinery

Magnusson
Alternating Currents

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EARLY HISTORY

The Brevard Street Mercury Arc Rectifier Substation of the Baltimore and Ohio Railroad is the first substation of this type in the South. The substation represents the latest design and application of engineering principles in accordance with American Railroad progress, towards which the Baltimore and Ohio Railroad has been a leading contributor.

Going back to the year 1888, the Baltimore and Ohio Railroad was seeking a means to serve it's customers more readily. At this time the railroad had no facilities thru the city of Baltimore for it's merchandise and passenger traffic. All trains over the Philadelphia division of the Baltimore and Ohio entered and left Baltimore by ferry transfer across the west branch of the Patapsco river, from Canton to Locust Point. The trains were then conducted thru the railway yards along the streets of South Baltimore to Camden Station.

A franchise was secured from the city of Baltimore in the early part of 1890 in accordance with the provision of a special act passed by the Maryland legislature, March 18, 1890 providing for the construction of a railroad thru the city. This road was known as the Belt Line and was to furnish a direct rail connection between the main line West of Baltimore and that East of Baltimore. The ordinance required that the trains be operated electrically, and since the railroad was to be underground, electric motive power provided the most satisfactory solution.

Thus the electrified Belt Line of the Baltimore and Ohio in the city of Baltimore is historically famous as it marked the first use of electric locomotives by any trunk line railroad.

The electrified portion of the Belt Line which lies within the

EARLY HISTORY

city limits of Baltimore begins at Camden Station on the west to the Waverly interlocking tower on the east, a distance of 3.75 miles. Forty-eight per cent of the total distance is thru tunnels. The longest section is the Howard Street tunnel from Camden Station to Mt. Royal Station comprising a length of 7300 feet.

Design and construction of a suitable power plant to furnish the necessary power was an interesting problem. The entire portion of the road to be handled by electric locomotives is upgrade, the difference in elevation amounting to 150 feet, giving an average grade of 0.9%, the ruling grade being 1.5% and maximum curvature $10^{\circ}$ 16'.

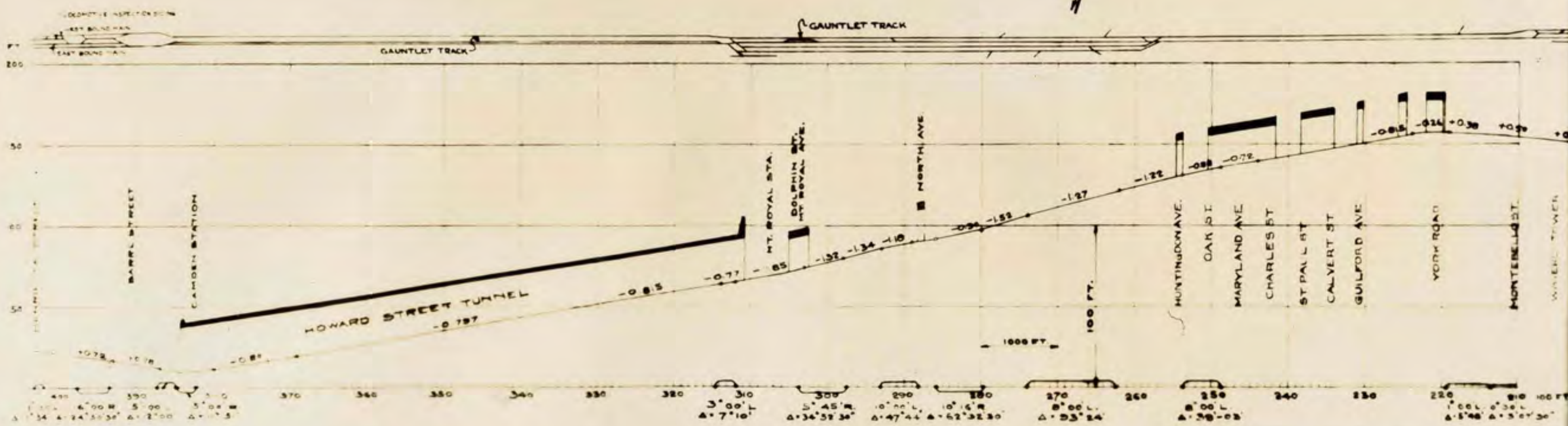
A power plant for supplying the necessary load was constructed at the western end of the line in 1894. The equipment consisted of five 500-k.w., 700 volt, direct-current generators direct connected to tandem-compound, non-condensing Corliss engines. This installation represented the largest direct connected generators ever installed up to that time. In addition to this layout, there was constructed a storage battery station near the Mt. Royal passenger station, one and three-quarter miles from the power house. (The site of the present rectifier substation.) The purpose of the battery substation was to improve voltage conditions by a booster system of control. The first trip with electric locomotive Number 1 was made June 27, 1894, and the line was opened for traffic May 1, 1895. One of the first electric locomotives used is still presented for exhibition as being the first electric locomotive used in this country under steam railroad conditions.

*(See picture showing map, profile and curvature of Belt Line on following page.)


MAP OF BELT LINE

ELECTRIFICATION EXTENDS FROM HENRIETTA ST. TO WAVERLY TOWER

APPROX SCALE 1" = 1000 FT.




TRACK CHART.
PROFILE & CURVATURE
OF
BELT LINE

REVISED TO SHOW GAUNTLET TRACKS, HOWARD ST TUNNEL AND TWIN TUNNEL, ALSO BREVARD ST RECTIFIER SUBSTATION - FEB. 10, 1926.

| | |
|---|---|
| B. & O. R. R. CO. | |
| BALTO MD | BELT LINE R.R. |
| MAP, PROFILE, CURVATURE, TRACK CHART OF ELECTRIFIED SECTION | |
| OFFICE OF ELECTRICAL ENGINEER | |
| BALTIMORE, MD. OCT. 1 1914 | |
| APPROVED ELECTRICAL ENGINEER | S-2275 A |

SUPERSEDES

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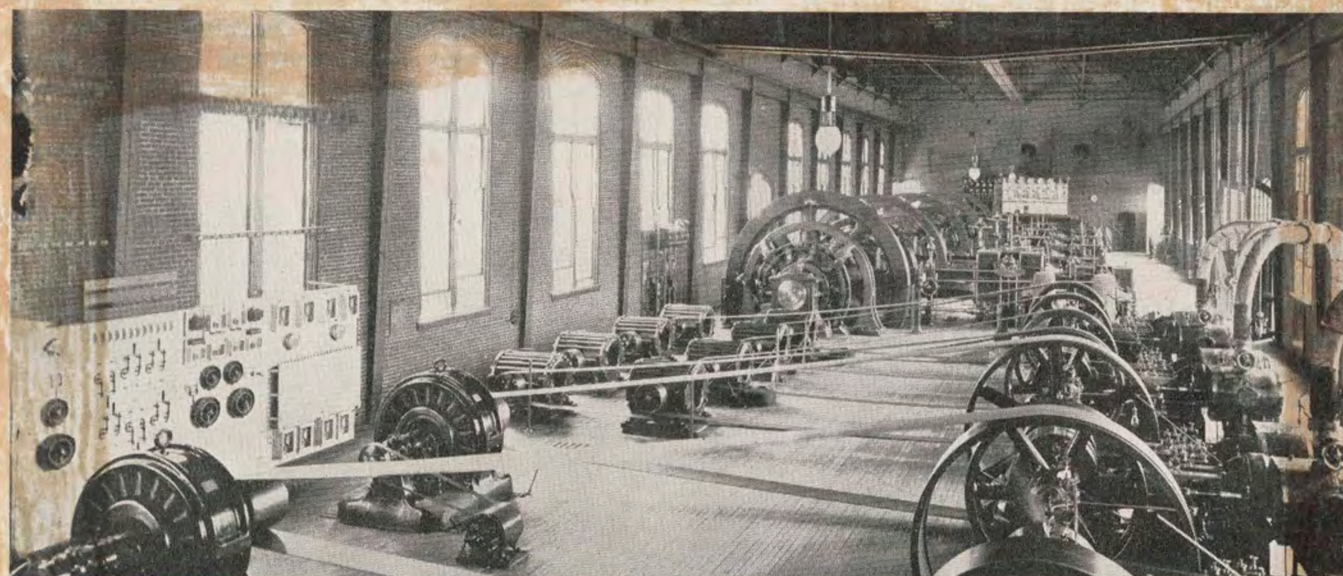
EARLY HISTORY

With increased traffic it soon became necessary to increase the power for the Belt Line and in 1909, the old power plant was found to be of insufficient capacity. This led to the construction of a rotary converter substation at the Mt. Royal end, near the battery station, in 1910. The converter substation consisted of three 1000 k.w., 650 volt synchronous converters with the necessary auxiliaries with space being provided for additional machines. The power was supplied by a local electric light and power company in the form of three phase, 13,000 volt, 25 cycle current. The battery station was retained for peak loads. In 1914, a 2000 k.w. converter was added and due to additional electrical improvements the battery station was dismantled. In 1915, the original power plant at the Camden Station end was abandoned.

In 1924, plans for the Howard Street extension were approved by the Maryland legislature. The rotary substation would then be in the center of the new street location. Since actual construction of the Howard Street extension was not scheduled to begin until some fourteen years later the railroad began planning for a new substation to supply the Belt Line.

Space was available for a new substation on adjoining property owned by the Baltimore and Ohio Railroad. However, this space was located directly above the Howard Street tunnel, and to construct a rotating substation on this site would subject the old walls of the tunnel to the vibration set up by rotating machines which, in all probability, they could not withstand.

Moving the substation to a more substantial site would involve considerable expense since additional units would have to be operated in



The original Baltimore and Ohio Belt Line power plant, built in 1894 and abandoned in 1915. In the far end of the building are the five 500-kw direct-current generators driven by direct-connected compound steam engines and supplying power to the railroad electrification. In the foreground are belted single-phase, 125-cycle, 120-kw generators for supplying power for lights and other station necessities.

EARLY HISTORY

order to supply the load while the remainder of the equipment was moved.

CONSTRUCTION OF THE RECTIFIER SUBSTATION

The Mercury Arc Rectifier seemed to offer a solution to this series of conflicting problems and in November 1937, construction of the Brevard Street Mercury Arc Rectifier Substation was under way.

It was possible to construct the Rectifier Substation directly over the tunnel since the foundation requirements were considerably less for rectifiers than for rotating machines. A much smaller and hence a less expensive building would be required. While construction on the new substation was being carried out, the old synchronous station continued to serve the load demand.

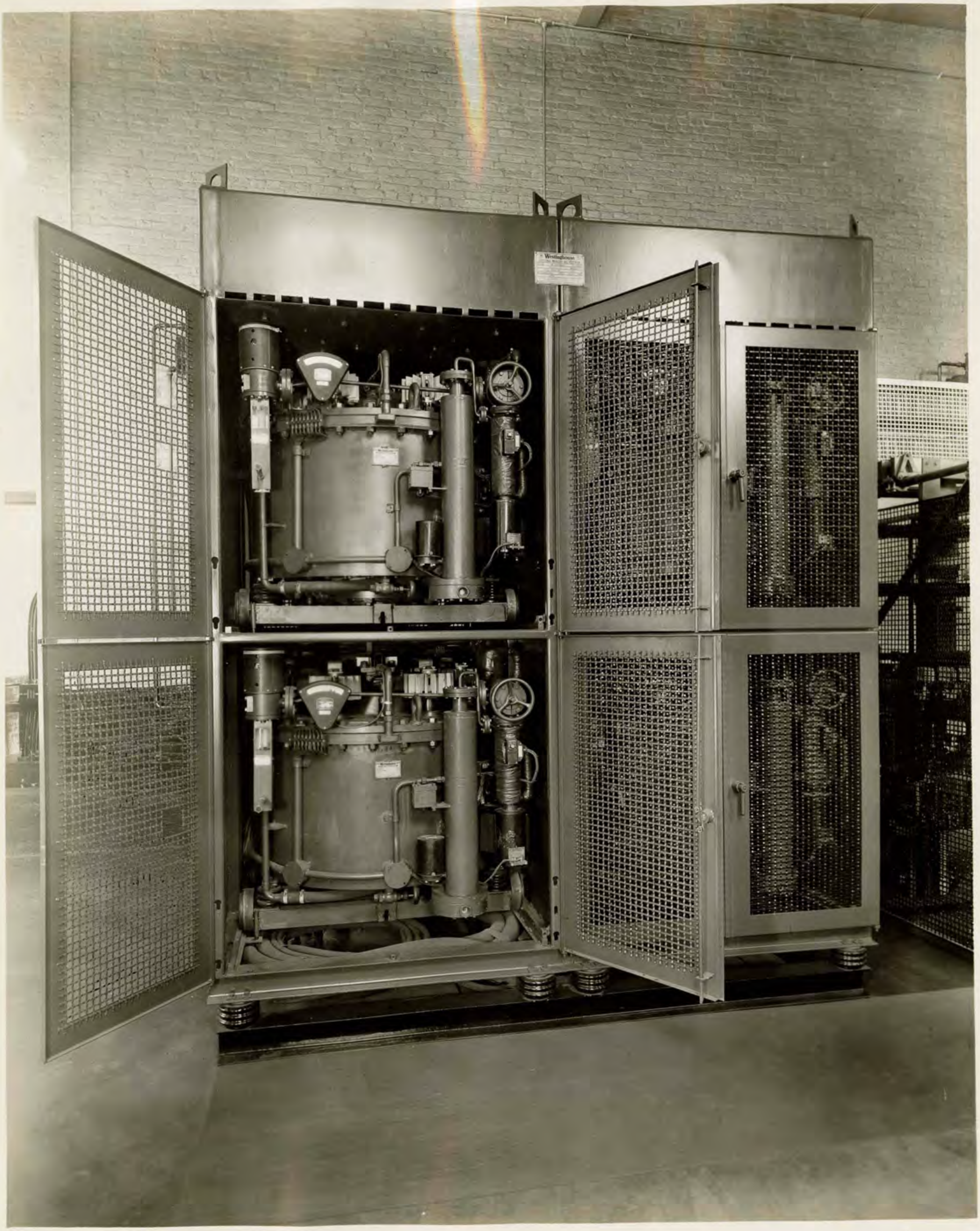
The new substation was designed to supply 670 volts direct current to the tunnel feeders with no interruption to service.

The substation capacity is 6000 k.w. which consists of two 3000-k.w. Westinghouse sectional mercury arc rectifier units. The mercury arc rectifier is at it's best in the smaller sizes because the arc path is smaller, hence a lower arc voltage, thereby decreasing the possibility of a breakdown voltage in the reverse direction. Therefore, each 3000 k.w. sectional unit is composed of four 750 k.w. rectifier tanks equipped with the necessary auxiliaries for operation.

*(See picture on following page showing comparison of sizes of the old and new substation. Also picture showing sectional units.)

On the left is the new Mercury Arc Substation.

The old Rotary Substation is shown at the right.



CONSTRUCTION OF THE RECTIFIER SUBSTATION

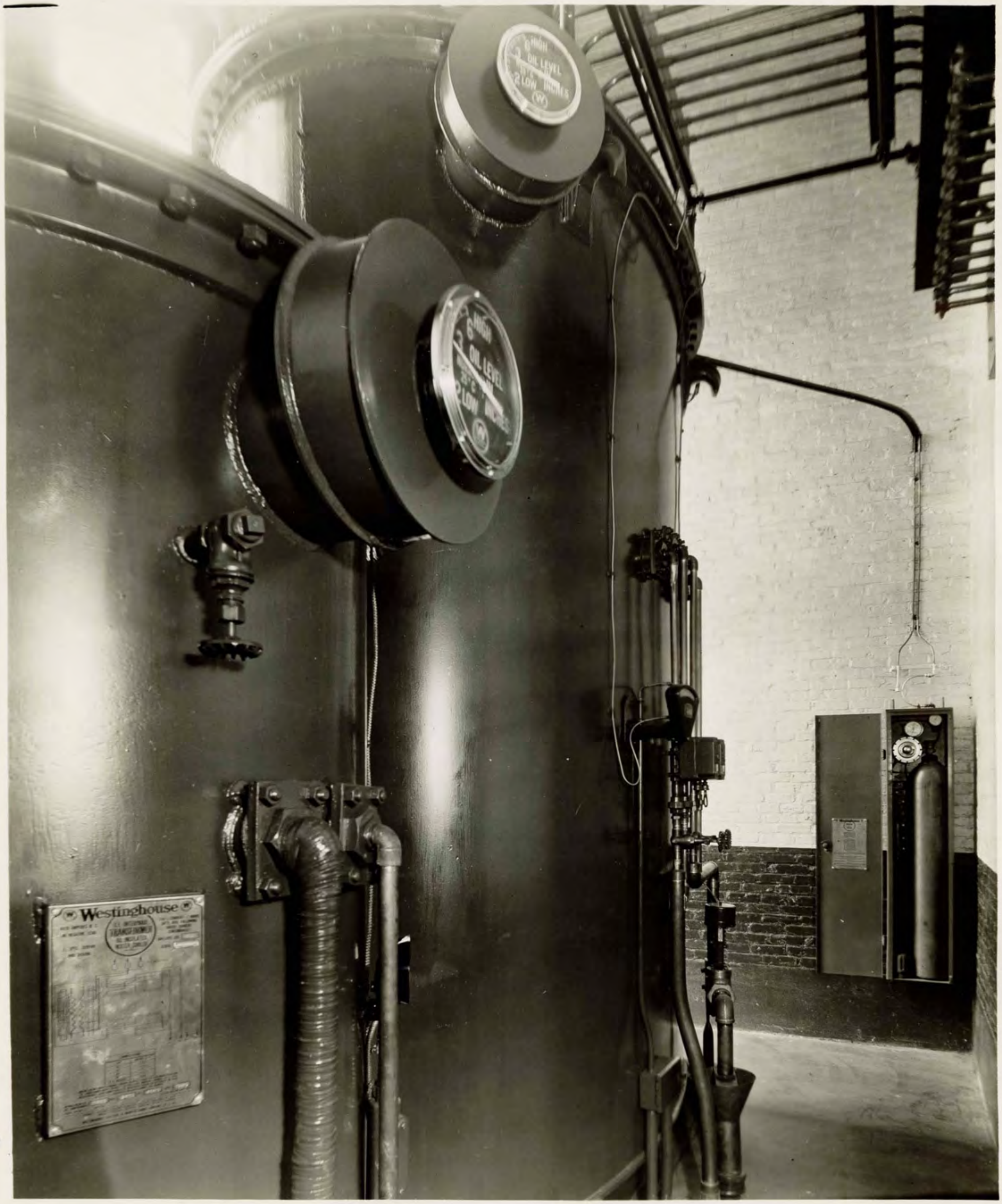
Each unit may be operated with two, three, or four tanks and the 3000 k.w. units may be operated independently or in multiple. Each unit will deliver 4478 amperes at 670 volts d.c. continuously, 150% load for two hours, and 300% load for five minutes. The auxiliary power supply is 240 volts, 3 phase 60 cycles. The total weight of each unit is 30,000 pounds when in operation. (The added operating weight being due to the necessary circulating water.)

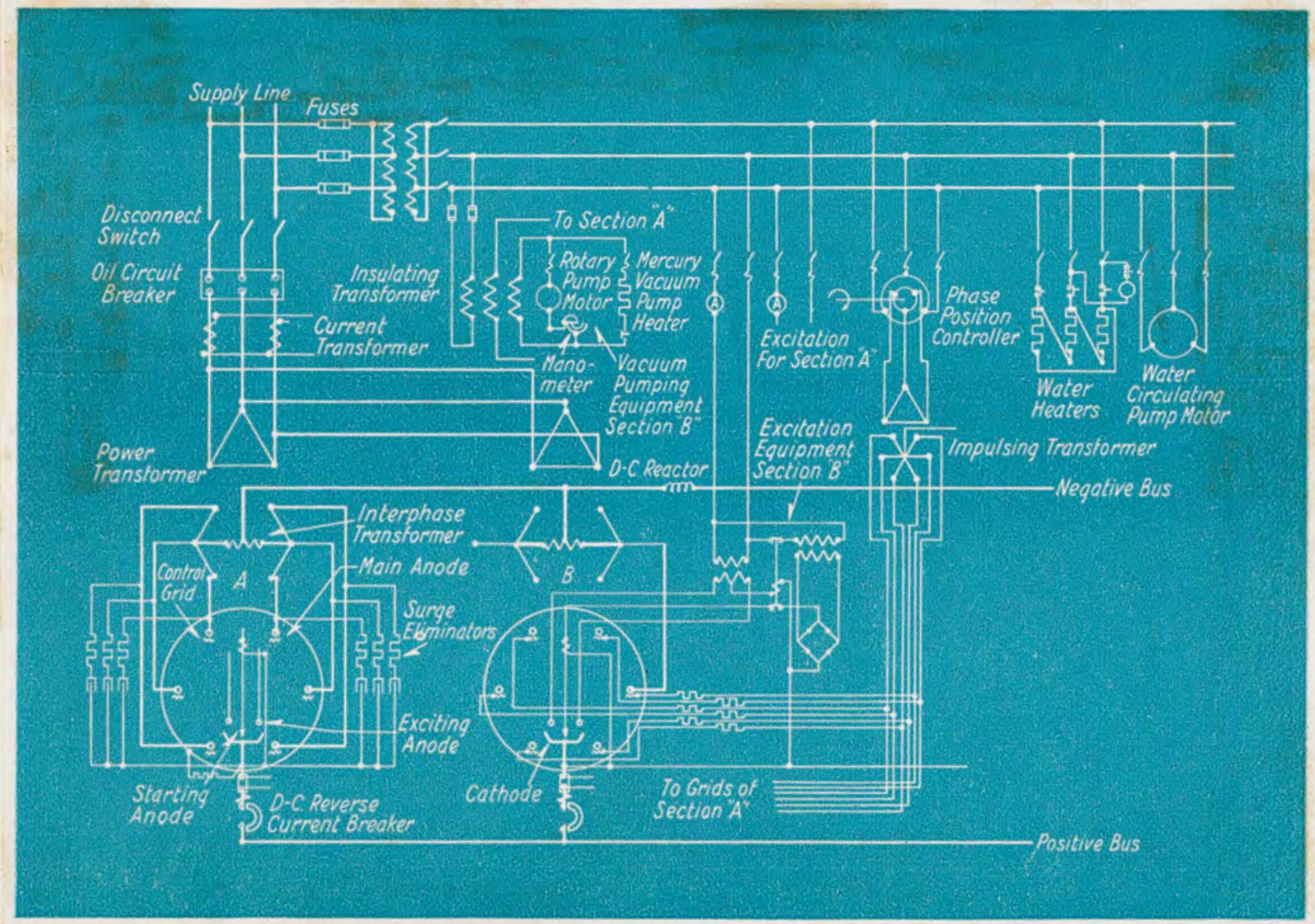
Power is supplied to each 3000 k.w. rectifying unit by a Westinghouse 3 phase rectifier transformer rated at 3240 kva, 13,200 volts to 613 volts, 60 cycle, impedance 4.8%, 12 phase, and zig zag secondary connections. This transformer is oil insulated, water cooled and has a total weight of 42,500 pounds. In conjunction with each main transformer is supplied a Westinghouse SL interphase transformer. The purpose of the interphase transformer is to give six or twelve phase operation of the rectifier with the advantages of three phase operation where the windings carry current for 120 electrical degrees or more. The interphase transformer is placed between the wye or zig-zag groups of the main transformer secondary so that the groups operate as three phase.

The interphase transformer is oil insulated, water cooled, and rated at 4478 amperes d.c. in the negative lead. The weight is 10,810 pounds.

Since the Mercury Arc Rectifier must be maintained at a definite temperature above a certain minimum value for best operation a recirculat-

*(See picture on following page showing main and interphase transformers. Also a schematic diagram of a typical two section Mercury Arc Rectifier Installation showing main transformer, interphase transformer and essential auxiliaries.)


HIGH
OIL LEVEL
LOW INCHES
Westinghouse


Supply Line
Fuses
Disconnect Switch
Oil Circuit Breaker
Current Transformer
Power Transformer
Insulating Transformer
To Section "A"
Rotary Pump Motor
Mercury Vacuum Pump Heater
Mano-meter
Vacuum Pumping Equipment Section "B"
D-C Reactor
Excitation For Section "A"
Excitation Equipment Section "B"
Phase Position Controller
Water Heaters
Water Circulating Pump Motor
Impulsing Transformer
Negative Bus
Interphase Transformer
Main Anode
Control Grid
A
B
Surge Eliminators
Exciting Anode
Starting Anode
D-C Reverse Current Breaker
Cathode
To Grids of Section "A"
Positive Bus

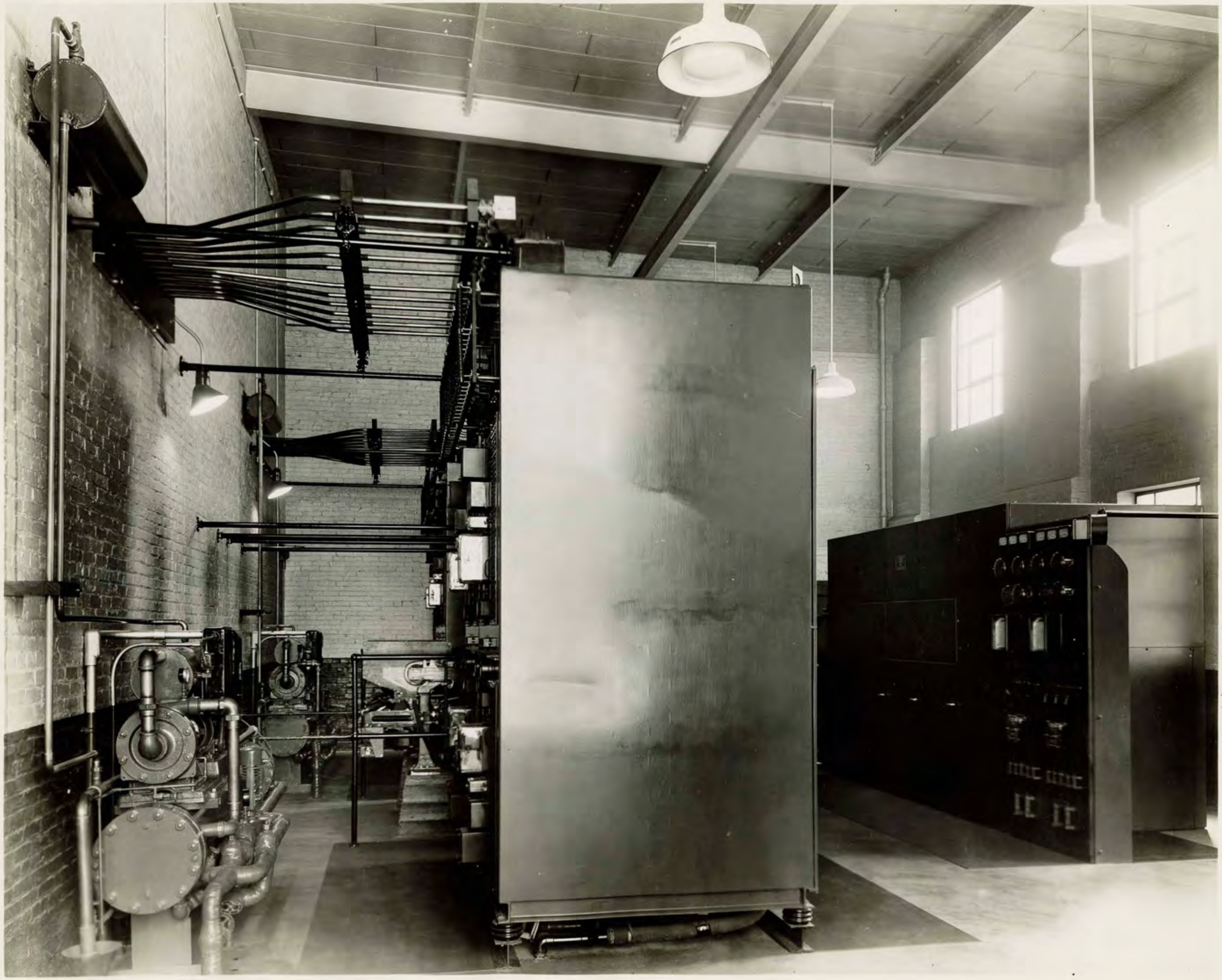
ing water system works in conjunction with a heat exchanger. Under normal operating conditions, the water is used to cool the rectifier below a certain maximum permissable operating temperature; but during periods of extremely low temperature it becomes necessary to heat the water in the heat exchanger. Each rectifying unit is provided with a Westinghouse heat exchanger. The heat exchanger has 133 square feet of heating surface. Circulation is provided by a 2 h.p., 220-440 volt, 3 phase, 60 cycle motor direct connected to a Gould centrifugal pump capable of delivering 35 gallons per minute, operating at 1750 r.p.m.--the maximum head being 66 feet. Above each heat exchanger is provided an expansion tank. The heater tank contains three Westinghouse CX-148, 4500 watt, 230 volt electric heaters. An accurate temperature control being maintained automatically. That is, the pump runs continuously and as soon as the temperature drops to a certain value the heaters are turned on automatically and cut out when the water is at the proper temperature.

Three phase, 60 cycle power is supplied to the substation, by the Consolidated Gas and Electric Company of Baltimore, thru two 13,200 volt underground feeders. The feeders enter the high tension oil circuit breakers--rated at 15,000 volts and 600 amperes. This also feeds two 25 kva, 13,200 volts - 220/110 volt 3 phase, 60 cycle transformers used for an auxiliary power supply. The main feeder circuits may be connected individually or in parallel to the rectifier equipment by means of a "dummy breaker" which is used as a disconnect switch. These five units are housed separately as metal clad units.

*(See picture on following page showing a view of the heat exchanger units.)

This picture shows the rear of the rectifier units showing the heat exchanger units and the high speed breaker as well as the conduit layout.

In front is a view of the metal clad switchgear and control panel.



## CONSTRUCTION OF THE RECTIFIER SUBSTATION

Alongside the metal clad switchgear is located the control panel. This panel contains two Esterline graphic wattmeters giving a graphic indication of the load on each unit during the day. There is also a d.c. voltmeter, 0-800 volt scale, for indicating the d.c. potential. Two a.c. kilovolt-meters for indicating the bus potentials, two a.c. ammeters, d.c. load ammeters, watthour meters, and overcurrent protective relays.

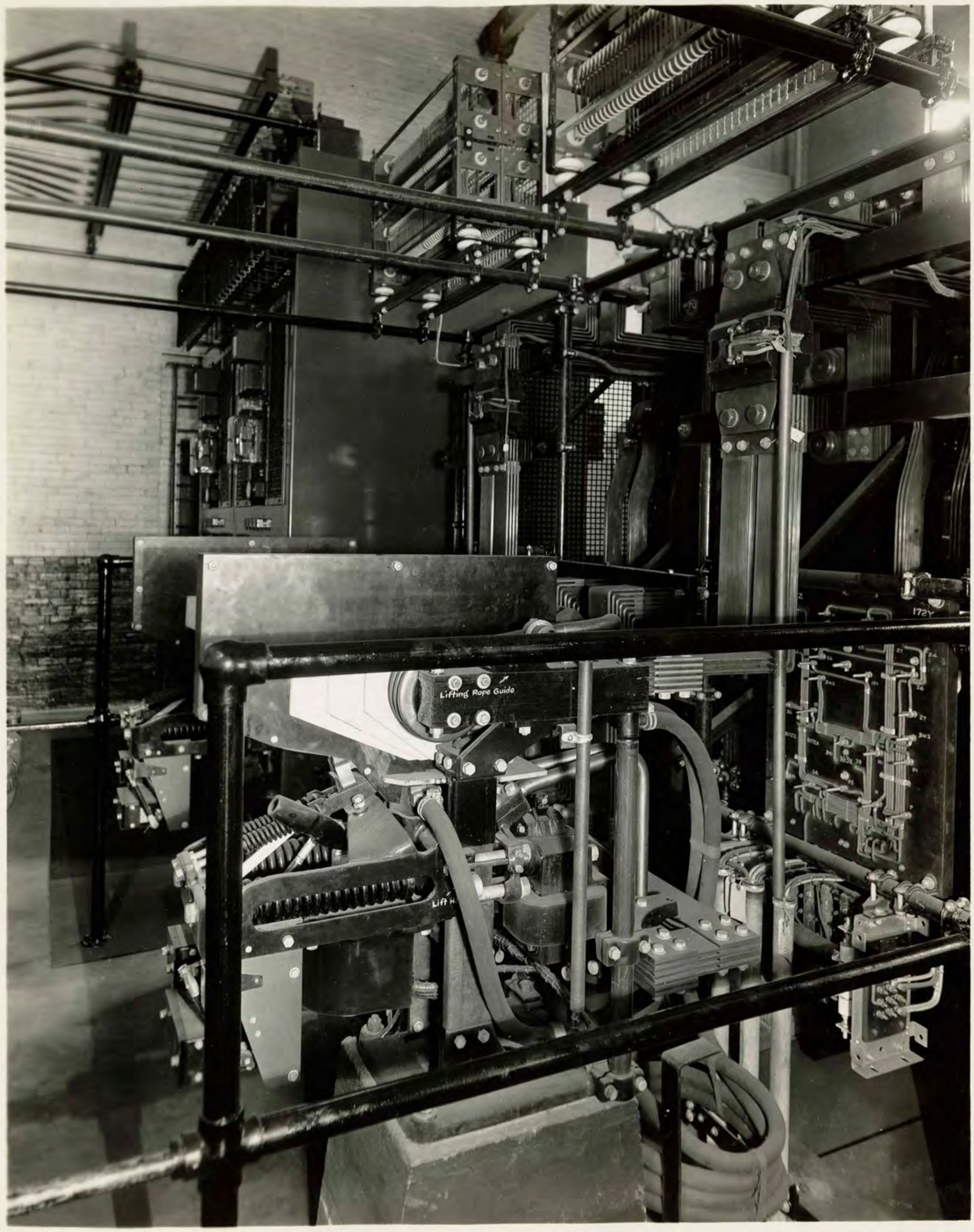
On the d.c. switchboard is mounted two 4 pole - 2000 ampere - 750 volt d.c. type CHR air circuit breakers and one 6000 ampere 650 volt d.c. breaker. Below this is mounted 2 - 6000 ampere 600 volt single throw knife switches.

For protection of the outgoing d.c. feeders and equipment against high momentary overloads due to some abnormal condition, it is desireable to disconnect the load as soon as possible. For this purpose the Westinghouse Electric Manufacturing Company developed a high speed water cooled breaker of 10,000 amperes and 750 volts. There are two such breakers mounted behind the d.c. panel.

Also included in the equipment is a "Degassing Unit" consisting of a SL Westinghouse degassing transformer of 30 kva capacity and a portable resister on wheels, for use in connection with the unit. The degassing unit is necessary as all of the foreign gases must be removed from the rectifier unit before it is suitable for operation at it's rated voltage.

An interesting feature is the method of heating the substation.

*(See picture on following page showing both rectifier units and d.c. panel. Also picture showing view of high speed breaker.)


Lifting Rope Guide
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CONSTRUCTION OF THE RECTIFIER SUBSTATION

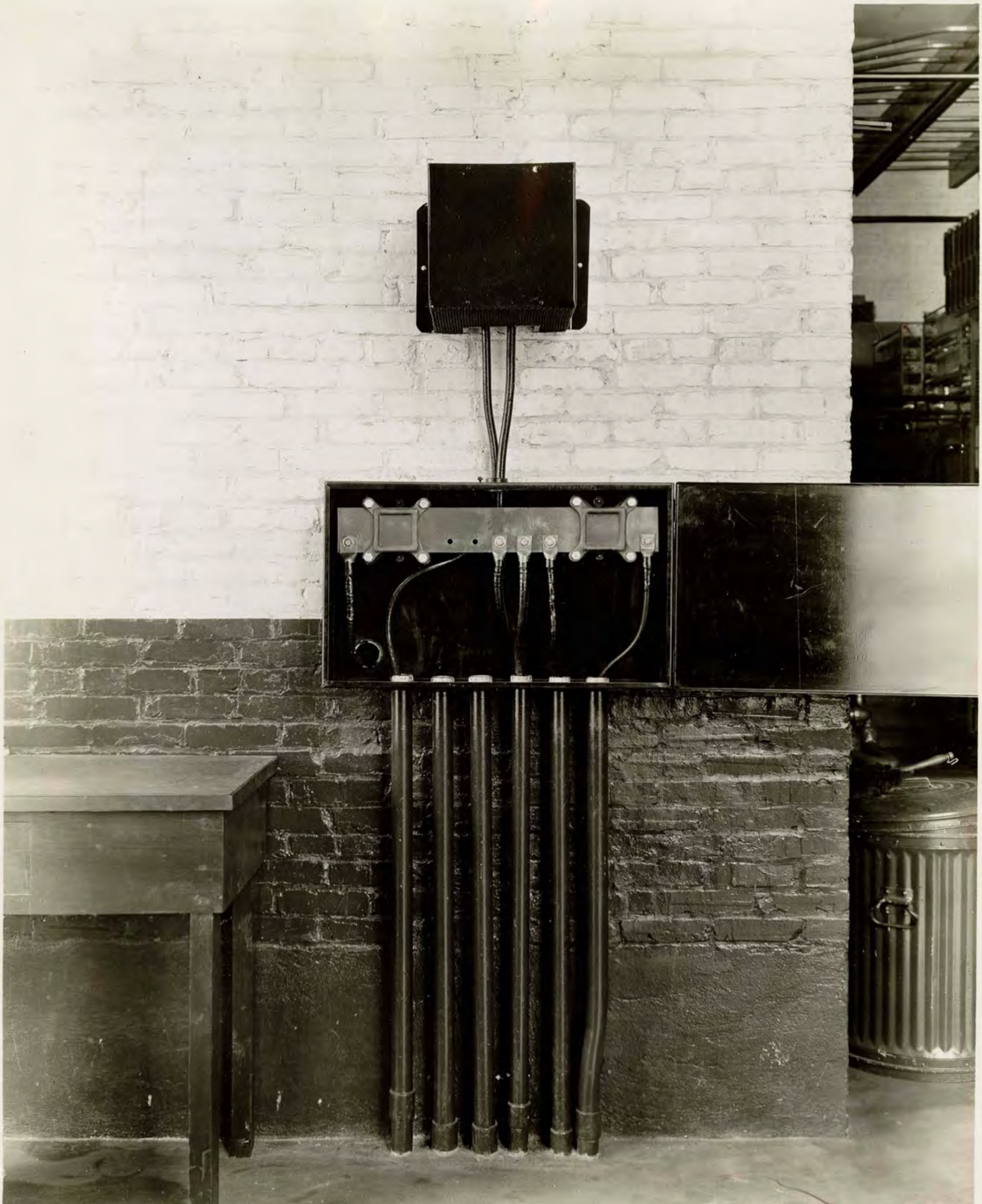
It is heated entirely electrically by two 20 k.w. Chromalox motor driven electric heaters and the transformer room by two $7\frac{1}{2}$ k.w. electric heaters contained in each transformer vault. The office is heated by a 5 k.w. 208 volt heater.

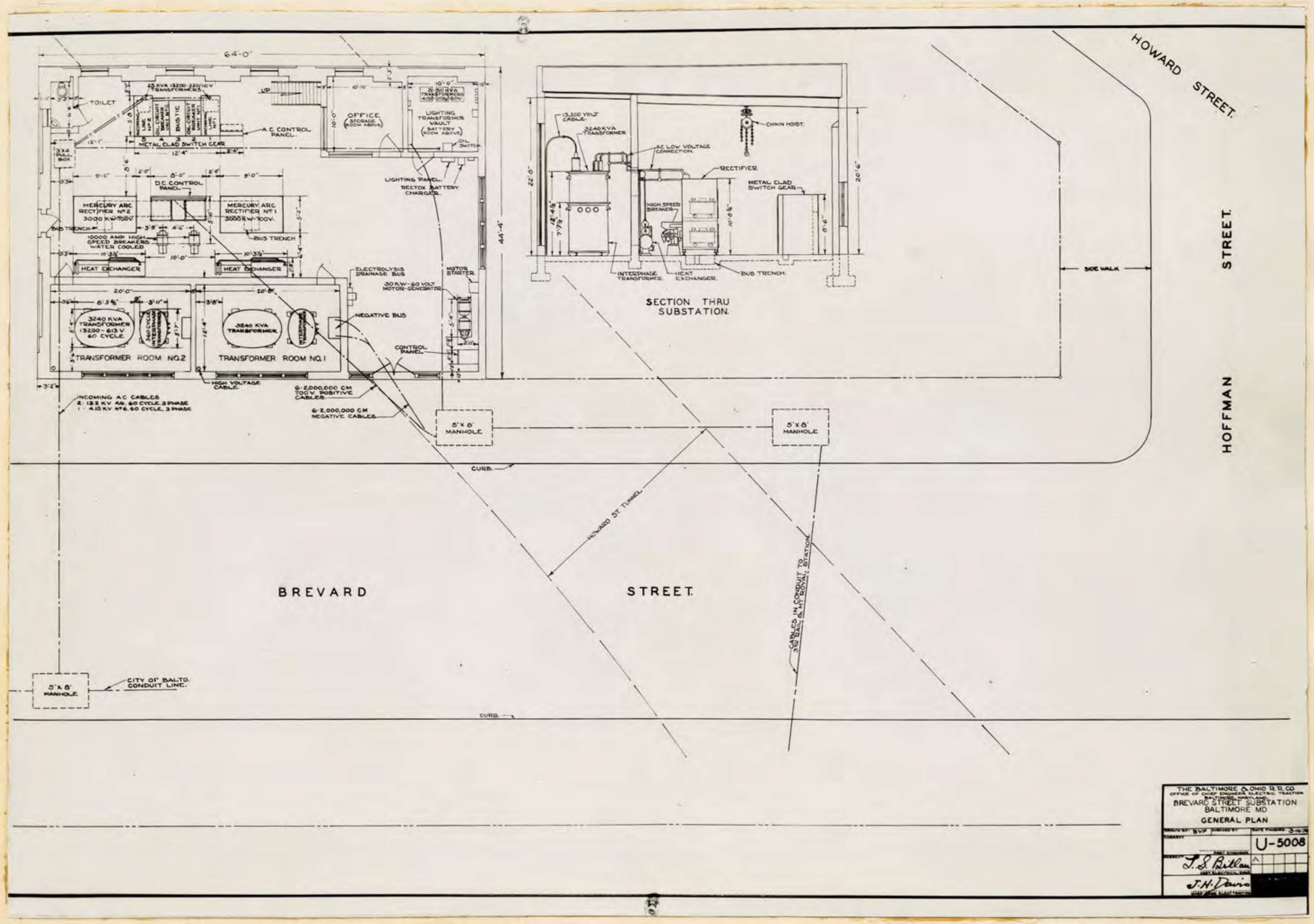
For lighting the substation and supplying lighting current for the Mt. Royal Station, there are three 50 kva single phase 60 cycle, 4160/120/208 volt transformers. Also to supply current for car battery charging purposes at Mt. Royal station, there is included a 30 k.w. 60 volt d.c. motor generator set.

The substation battery which supplies control current for various operating devices in connection with the substation operation, is charged thru rectox units from 208 volts a.c.

Also included in the construction and equipment of the substation is an "Electrolysis Bus" mounted in a cabinet on the wall. The purpose of this bus is to aid in studying electrolytic problems. The substation ground is connected directly to the bus and connections of all the water mains, gas lines, and conduits are also made to the bus. In order to determine the flow of current between any of these circuits and ground, the desired circuit is removed from it's bus connection and an instrument is inserted.

*(See picture on following page showing Electrolysis Bus. Also sectional and floor plan of the substation showing location of all equipment.)





HOWARD STREET
TOILET
25 KVA 13200-220/110V TRANSFORMERS
UP
OFFICE (STORAGE ROOM ABOVE)
LIGHTING TRANSFORMER VAULT (BATTERY ROOM ABOVE)
3-50 KVA TRANSFORMERS 4150-208/120V.
OIL SWITCH
A.C. CONTROL PANEL.
METAL CLAD SWITCH GEAR
3'x4' PULL BOX
D.C. CONTROL PANEL
MERCURY ARC RECTIFIER Nº 2 3000 KW-700V
MERCURY ARC RECTIFIER Nº 1 3000 KW-700V.
BUS TRENCH
10000 AMP HIGH SPEED BREAKERS WATER COOLED
HEAT EXCHANGER
HEAT EXCHANGER
LIGHTING PANEL.
RECTOX BATTERY CHARGER.
ELECTROLYSIS DRAINAGE BUS
MOTOR STARTER.
30 KW-60 VOLT MOTOR-GENERATOR
NEGATIVE BUS
CONTROL PANEL.
3240 KVA TRANSFORMER 13200-613 V. 60 CYCLE
3240 KVA TRANSFORMER
INTERPHASE TRANSFORMER
TRANSFORMER ROOM NO.2
TRANSFORMER ROOM NO.1
HIGH VOLTAGE CABLE.
64'-0"
44'-4"
INCOMING A.C. CABLES
2 - 13.2 KV 4/0, 60 CYCLE, 3 PHASE
1 - 4.15 KV Nº6, 60 CYCLE, 3 PHASE
6-2,000,000 CM 700 V. POSITIVE CABLES
6-2,000,000 CM NEGATIVE CABLES
5'x8' MANHOLE
5'x8' MANHOLE
13,200 VOLT CABLE
3240 KVA TRANSFORMER
A.C. LOW VOLTAGE CONNECTION
CHAIN HOIST.
RECTIFIER
METAL CLAD SWITCH GEAR
HIGH SPEED BREAKER
INTERPHASE TRANSFORMER
HEAT EXCHANGER
BUS TRENCH
SECTION THRU SUBSTATION.
SIDE WALK
HOFFMAN STREET
CURB
HOWARD ST. TUNNEL
CABLES IN CONDUIT TO 3rd RAIL & HT ROYAL STATION
BREVARD STREET
5'x8' MANHOLE
CITY OF BALTO. CONDUIT LINE.
CURB
THE BALTIMORE & OHIO R.R. CO.
OFFICE OF CHIEF ENGINEER ELECTRIC TRACTION
BALTIMORE, MARYLAND
BREVARD STREET SUBSTATION
BALTIMORE MD
GENERAL PLAN
BVP
U-5008
T. S. Billau
J. H. Davis

## THEORY OF OPERATION OF THE MERCURY ARC RECTIFIER

In gaseous conduction of electricity, the movement of electrons toward an anode and of the positive ions towards the cathode, constitutes the flow of current between the electrodes. The voltage required for gaseous conduction between two electrodes depends primarily on the gas or vapor pressure, and on the temperature of the material of the electrodes.

In the Mercury arc rectifier, the cathode or electron emitting material is mercury. The advantages of mercury when used for this purpose are:

(1) The voltage required to release the electrons from the mercury surface at the operating temperatures is less than that required by other materials.

(2) Mercury vapor in the vacuum chamber increases ionization by collision.

(3) Ionized mercury atoms are attracted to the mercury pool cathode and the heat produced by collision increases the cathode temperature.

(4) Any condensation or change in the quantity of mercury vapor in the chamber is automatically adjusted by the cathode mercury pool.

(5) The mercury arc terminating on the cathode surface produces an intensely hot cathode spot which moves rapidly over the surface of the mercury pool. The high temperature (approximately 2000°C) of the cathode spot is of importance in producing the rapid emmission of electrons without causing deterioration of the cathode surface.

The unidirectional flow of current thru the rectifier is due largely to the difference in temperature of the two electrodes. The cathode

THEORY OF OPERATION OF THE MERCURY ARC RECTIFIER

being brought to a state of rapid electronic emission while the anode is maintained at a temperature at which electrons cannot be emitted.

The anode or positive terminal of the rectifier is usually graphite because graphite is capable of withstanding the high operating temperatures more readily than other available materials.

Gases other than mercury vapor in the rectifier prove to be detrimental to the efficient operation. Collisions with electrons are not elastic with common gases, consequently power losses are higher. The presence of oxygen is particularly undesireable since this gas combines with mercury under arc conditions and produces compounds which would interfere with the operation and in time destroy the mercury cathode.

*(See diagram on following page.)

Figure 1. Shows a single phase full wave rectifier. When the current in the primary of the single phase transformer is in one direction, to the right, on the positive half of the cycle; the current in the secondary flows to the left in the opposite direction thru anode 1 to the load. On the next half of the cycle, the current in the primary is reversed causing the current in the secondary to flow thru anode 2 and thru the load in the same direction as before. Thus a pulsating direct current is produced from alternating current.

Figure 2. Shows a three phase rectifier. The primary of the transformer is delta connected and each leg of the wye secondary is connected to an anode. In three phase rectification there will be three currents differing in conduction periods by 120 electrical degrees. Hence, a

smoother direct current is produced. For a greater number of phases, the conduction period of each anode is decreased and less pronounced becomes the ripple in the d.c. voltage produced. This can readily be seen by comparing Figure 1 and Figure 2 with Figure 3.

## DESCRIPTION OF THE RECTIFIER

The metal tank mercury arc rectifier of the type used in the construction of the substation consists essentially of a gas tight steel container which contains solid electrodes, or anodes, and a single electrode of mercury. The tank itself is constructed of special steel plates which are welded tight. All seams are welded on the inside, and the tank is constructed so that there is access to all of the interior parts for proper maintenance. The joints that are made separable are fitted with special gaskets to prevent leakage. The main and auxiliary anodes, as well as the control grid leads, enter the vacuum chamber thru porcelain bushings, soldered tight to the tank by a special process. The anodes are of a high quality graphite. The cathode, or mercury pool, is contained in a steel dish which is insulated from the tank by an insulating ring and vacuum sealed to the tank.

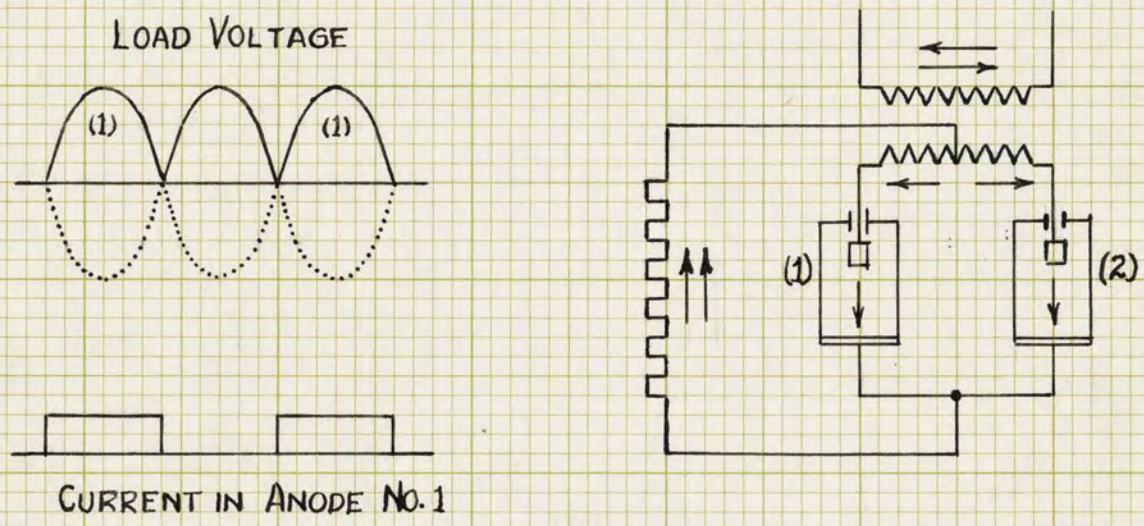
The tank is surrounded with a steel water jacket for maintaining the proper temperature of the rectifier for efficient operation.

In order to maintain the mercury arc rectifier at the proper vacuum which is of prime importance, there is included a mercury vapor

# DIAGRAMS SHOWING THE PRINCIPLE OF OPERATION OF THE MERCURY ARC RECTIFIER

FIG. 1

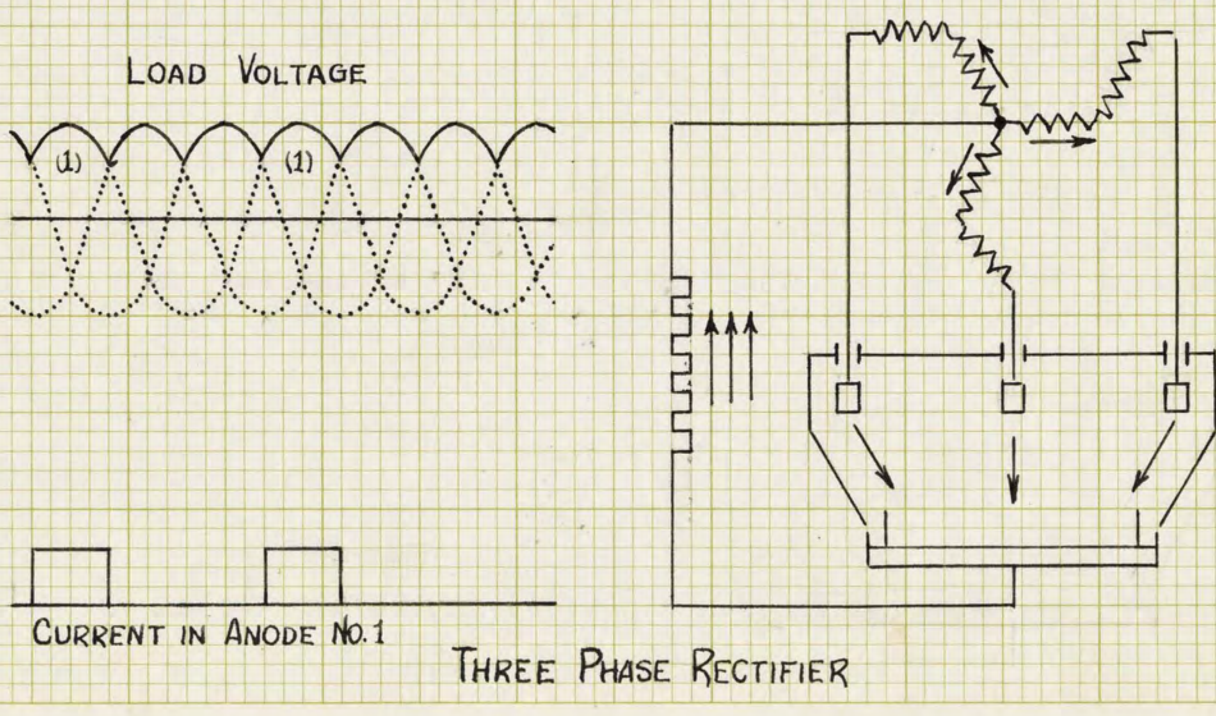
CONDUCTION PERIOD OF EACH ANODE IS 180 DEGREES




SINGLE PHASE FULL WAVE RECTIFIER

FIG. 2

CONDUCTION PERIOD OF EACH ANODE IS 120 DEGREES

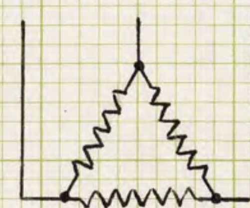



THREE PHASE RECTIFIER

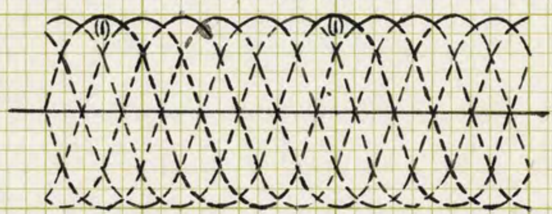
# Diagrams Showing the Principle of Operation of the Mercury Arc Rectifier

Fig. 3

Conduction Period of Each Anode is 60 Degrees



Load Voltage



Current in Anode No. 1

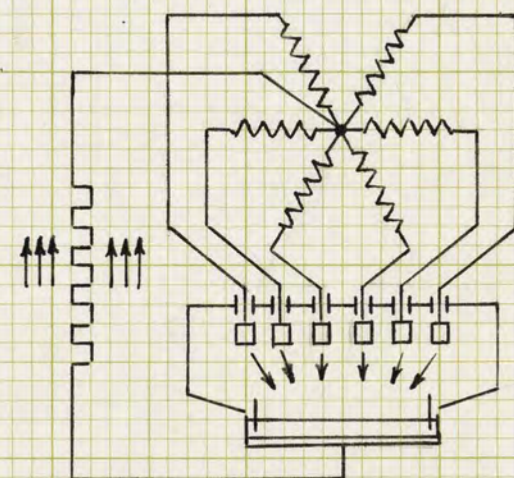
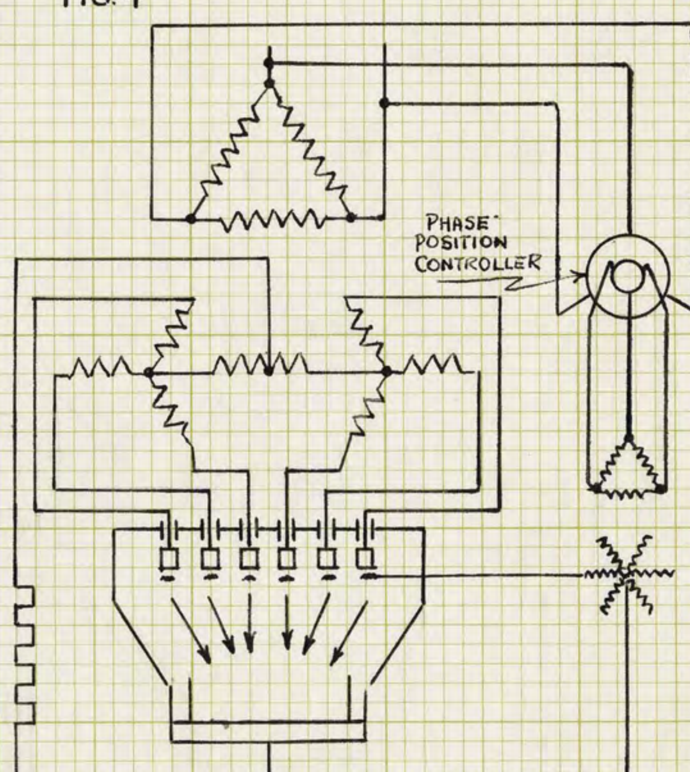
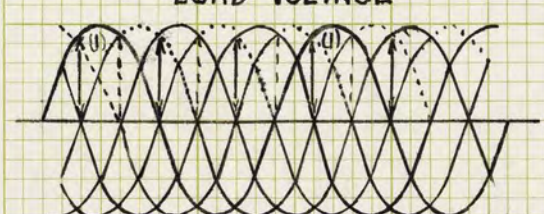


Diagram of a Six Phase Rectifier

Fig. 4




Load Voltage



Current in Anode No. 1

Diagram Showing the Effect of Energized Grids in Controlling the Output Voltage of a Rectifier

DESCRIPTION OF THE RECTIFIER

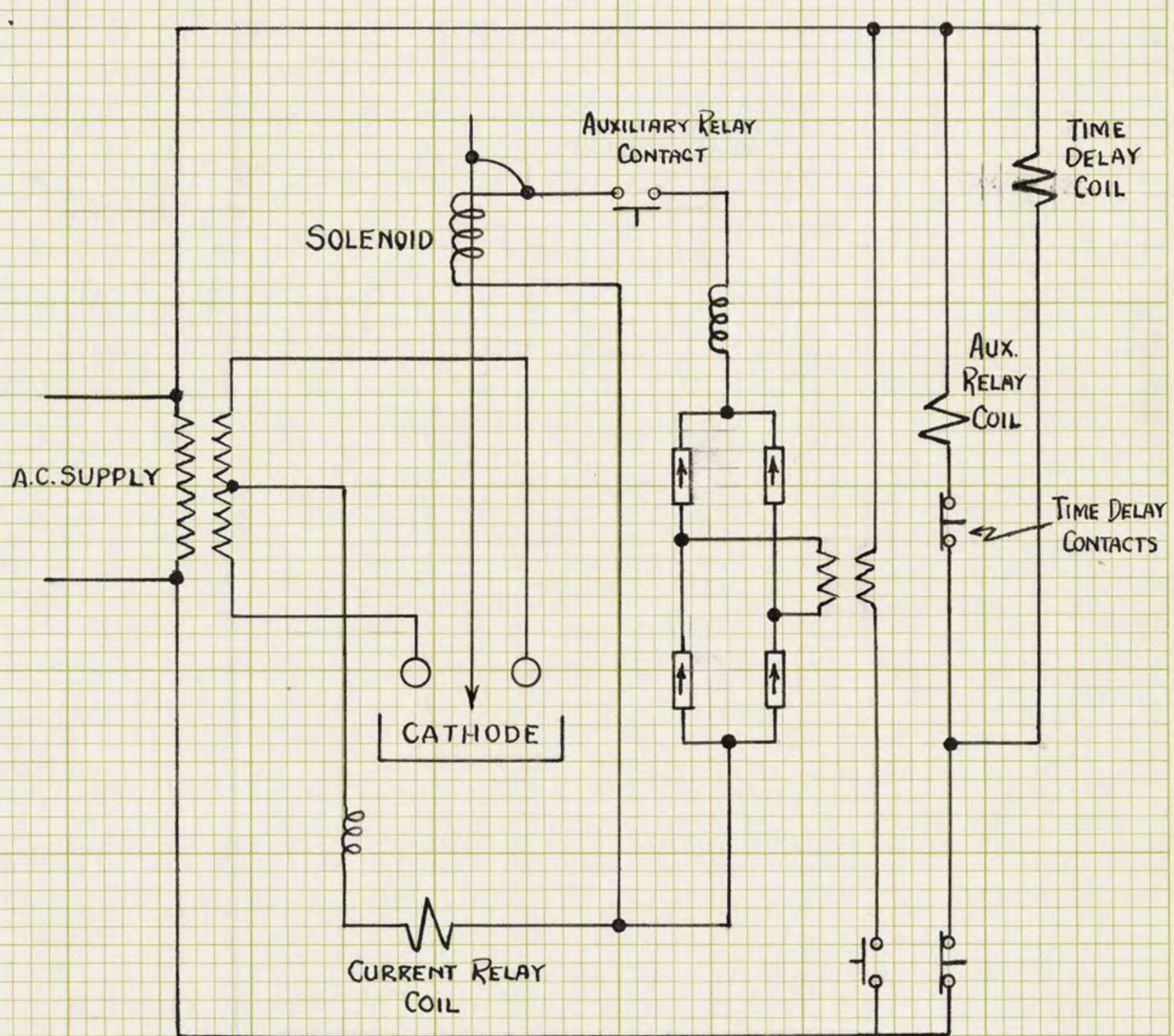
vacuum pump. This vacuum pump pumps gas from the section and discharges it thru a barometric tube into an interstage reservoir. From here the gas is pumped thru a float operated vacuum valve into a rotary oil-sealed backing pump which discharges it at atmospheric pressure.

The mercury vapor pump is capabable of evacuating the vessel to a very low pressure which is in the order of a fraction of a micron. (A micron is that pressure which will support a column of mercury 0.001 millimeter high. Since atmospheric pressure is 760 millimeters. One micron is 1/760,000 of an atmosphere.) The pump will not pump against a high back pressure. The pressure maintained within the section is indicated by vacuum gauges of special construction and the proper pressure is maintained by means of contact making pressure gauges. This equipment is classed as the rectifier auxiliaries.

In the process of loading a mercury arc rectifier, the first step is to bring the cathode into an active state of electronic emission. This is accomplished by means of the ignition and excitation equipment which starts the arc in the vacuum chamber. The starting is accomplished by depressing a steel rod into the mercury by action of a solenoid and withdrawing it. The solenoid is connected in parallel with the starting rod. When the solenoid circuit is energized thru the control transformer and relay contacts the steel rod is plunged into the mercury. This short circuits the solenoid and by the action of a spring, the rod is withdrawn, thereby drawing an arc. As soon as this happens, the excitation anodes which are supplied by a small transformer, pick up and maintain the cathode spot.

*(See following page showing a schematic diagram of connections of the control and excitation system.)

# Schematic Diagram of Connections of the Starting and Excitation System of a Mercury Arc Rectifier



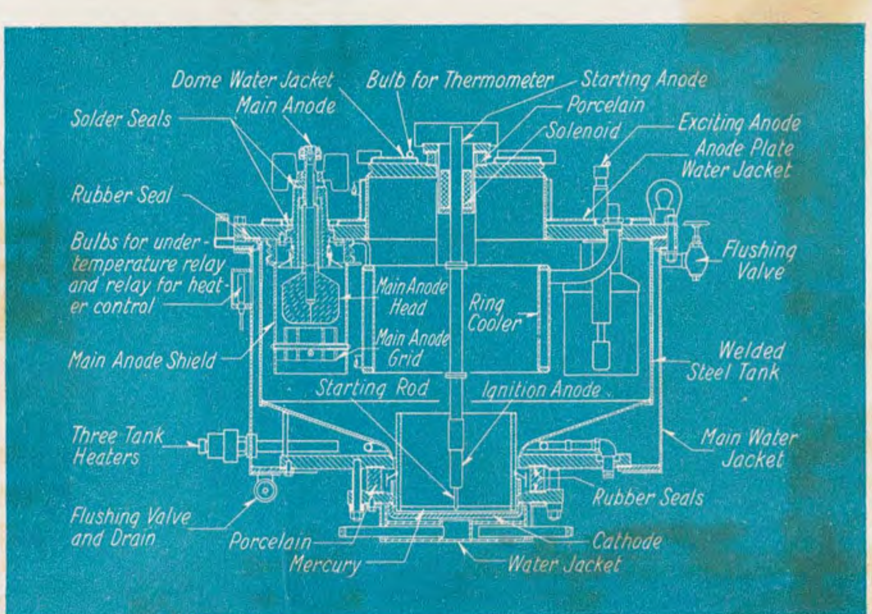
## DESCRIPTION OF THE RECTIFIER

The excitation anodes maintain the cathode spot in absence of the main load. In case the arc is extinguished for some reason, it is started after a time delay automatically--requiring no restarting by an operator.

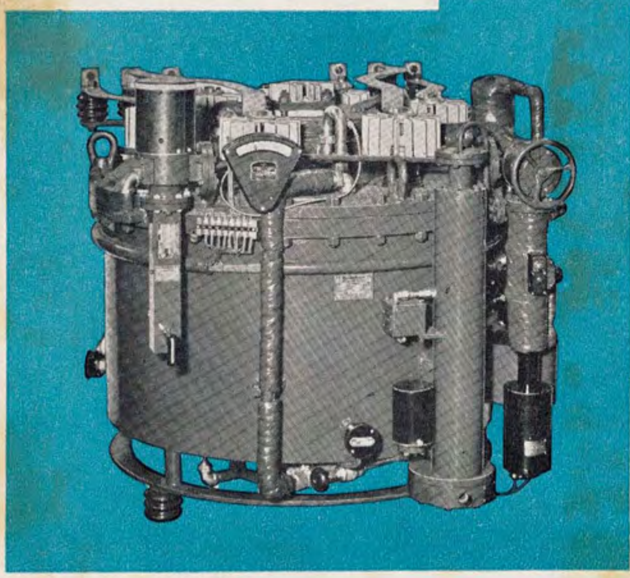
## THEORY OF OPERATION OF THE MERCURY ARC RECTIFIER

Although during operation, the anodes of a rectifier will withstand appreciable negative voltage without formation of a cathode spot on the anode, which will cause a breakdown in the reverse direction, they will not reliably withstand the high voltage of operation unless some provision is made to establish the required gradient and to deionize the gas surrounding the anodes after a conduction period. For this purpose, the anodes are surrounded by shields and energized grids. The grids are in the arc path to each anode, and by placing a potential on the grid that is negative with respect to the cathode, an anode may be prevented from picking up current. Changing the grid potential from negative to positive, the anode is released to carry current; and by controlling the time of this change, the anode pick up may be delayed beyond it's normal time in each cycle. (See Figure 4 on page 24.)

*(See diagram on followin page showing a crossectional view of the rectifier section showing operating parts.




Cross-sectional View of Rectifier Section.



750 k.w., 600 volt
Mercury Arc Rectifier.

## REGULATION

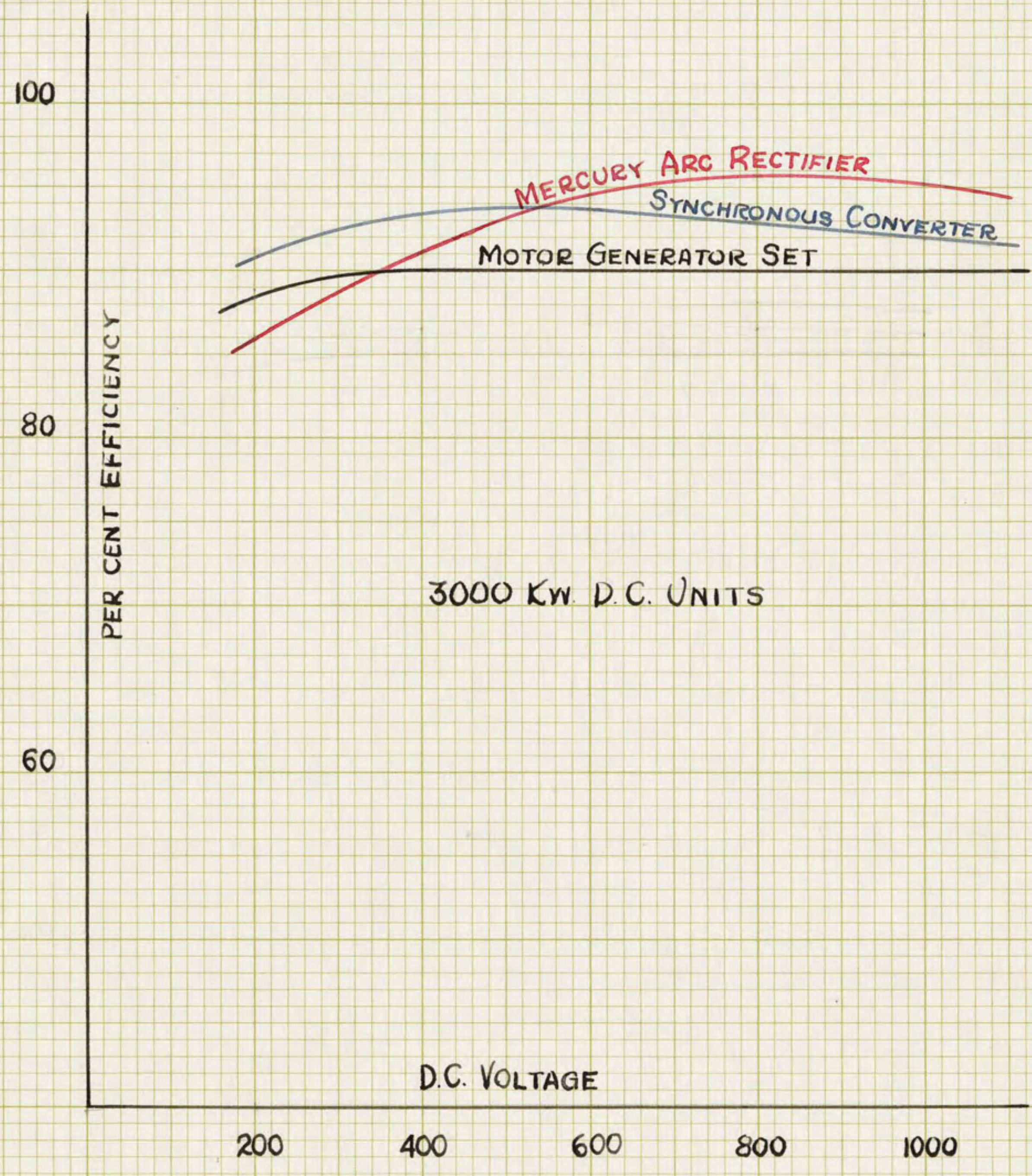
The normal rectifier unit has a slightly drooping voltage characteristic. The output voltage being determined by the transformer secondary voltage and the connections used. However, it is influenced by the arc drop in the rectifier and the reactive drop in the transformer supply circuit. The arc drop is nearly constant throughout the load range and the regulation is in the order of 5% to 6%.

The normal characteristics are altered by the use of control grids, mentioned previously. This control is accomplished by the application, to the grids, of impulse voltages that are synchronized with the power supply to the main anodes. The transformer is designed to provide the highest voltage desired and the d.c. output is reduced from that value by delaying the point of pick up by shifting the phase position of the impulsing supply, or by applying a bias voltage to alter the point on a sine wave impulse at which pick up takes place. This delay action is brought about automatically with a voltage regulator. This method of control provides an extremely smooth variation of voltage output.

## EFFICIENCY

The efficiency of a mercury arc rectifier unit is the ratio of the power output at the d.c. terminal to the power input at the high tension terminals of the transformer. The component losses of the unit included in the efficiency calculations are, copper and iron transformer losses, loss in the rectifier arc and the power for operation of the rec-

CURVES SHOWING THE RELATION OF EFFICIENCY OF THREE TYPES OF CONVERSION APPARATUS WITH VARIATION IN D.C. VOLTAGE.



## INSPECTION AND MAINTENANCE

Inspection of apparatus in a completely automatic substation, as described, is an important factor towards continued service without delays. The frequency of inspection depends primarily upon the nature of the equipment and the quality of inspection. It has been the practice of the operators in the Brevard Street substation to make detailed inspections at least once a week, in order that all apparatus receives the best possible attention and care. At the substation, there are all of the circuit diagrams and schematic diagrams suitably framed, to enable the operator to locate any trouble that might develop during regular operation. Of course, certain routine inspections are carried out by each operator in turn during regular operation. In such a manner, all parts that begin to wear are noted and repaired when time permits.

In the maintenance of the equipment is included the cleaning of relay contacts and operating devices. Keeping moveable parts well lubricated and replacing worn contacts and faulty wiring. All protective devices are frequently tested and adjusted whenever necessary.

## CONCLUSION

The Brevard Street Mercury Rectifier Substation was opened for traffic in March 1938. An average of 7,000,000 gross ton miles is handled over the Belt Line each month, the electric locomotive mileage being about 19,500 and the total k.w. load used each month being about 500,000.

Today, to supply such a load, the mercury arc rectifier is replacing the rotating equipment because it offers a reliable means of con-

CONCLUSION

version of alternating current to direct current. Such applications include direct current for railways, and many industrial uses.

Because of the excellent performance due to design improvements, making it possible to supply loads of several thousand kilowatts at high d.c. potentials ranging up to 20,000 volts, the rectifier is faster becoming more widely used. Grammar

As brought out by the efficiency curves and discussion covering the comparison of rotating machines to rectifiers--the rectifier gives a much lower operating cost. Few replacement parts give low maintenance cost.

Noiseless operation and the ability of the rectifier unit to take on and deliver a power demand immediately, without the need of synchronization or switching, is definitely an "Engineering Achievement."

As a final comparison, the Table following gives a summary of the Engineering Economics involved, leading up to the present installation.

# CONCLUSION

| | Belt Line Power Plant (1894) | Rotary Converter Substation (1910) | Mercury Arc Rectifier Substation (1938) |
|---|---|---|---|
| Capacity of Equipment, k.w. | 2,500 | 5,000 | 6,000 |
| Size of Building - Electric Power | 126 ft. x 55 ft. x 24.5ft. | 96.6 x 31.5ft x 36.2ft. | 61.6 x 41ft. x23.2ft. |
| Floor Space - Sq. Ft. Generators | 6,930 | 6,090 | 2,749 |
| Cubic Contents (cu. ft.) Electric Power only | 169,785 | 110,381 | 58,788 |
| Cu. Ft. per k.w. Capacity Electric Power | 68 | 22.2 | 9.8 |
| Relative Unit Size (Cu. ft. per k.w.) in % | 100 | 32.7 | 14.5 |

This tabulation brings out the fact that it is now possible to concentrate more power in a much smaller space. Using the old Belt Line power plant as a basis of 100%, denoting the floor space in cubic feet per kilowatt, it follows the fact that the Rotary Substation required only 32.7 % compared to the present installation of 14.5%.